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(54) METHODS OF AND APPARATUS FOR CONTINUOUS FREEZE-DRYING

(71) We, YUKIO SAHARA, 5—8, Kori Shinmachi, Neyagawa City, Osaka Pref., Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to methods of, and apparatus for, freeze-drying various fresh food and medical stuffs, and in its more particular aspects it has to do with fully continuous freeze-drying of such stuffs with higher efficiency and effectiveness but lower cost than batch-type and semi-continuous freeze-drying.

It is known that freeze-drying is a preferable treatment for preservation of fresh food and medical stuffs which have high water contents or are very unstable to heat, because freeze-drying not only keeps the shape, colour, nutriment, taste and other natural properties of such stuffs mostly intact but also allows such stuffs to return to the original conditions rapidly with a mere addition of moisture.

The general method of freeze-drying is that a frozen object or charge of material is heated in a substantial vacuum of 0.1 to 0.001 mm HG to sublimate the frozen water content out of the object, thus obtaining a porous solid dried product. It is therefore indispensable to freeze-drying treatment that the object is heated in the vacuum sufficiently for such sublimation of water content.

In conventional freeze-drying, a heating means is provided within each vacuum container which is connected to a vacuum pump, and the frozen objects are charged into the vacuum containers and the dried objects are discharged out of them in batch-type operation. The heating may be either external or internal. Where external heating is used this is such that the object is heated by the introduction of heat from the outside of the object, for instance by means of heating tubes in which steam or other similar heating medium is circulated. In the external heating the exterior portions of the object will be heated and dried inevitably prior to the interior portions, and therefore heat will be transferred into the interior undried frozen portions by way of the exterior dried porous portions where heat conductivity is already considerably lowered. Thereby not only will interior drying be delayed but also the temperature of the object will be so far from easy control as to cause overheating in the exterior portions. Where internal heating is used this is such that the object is heated by the creation of heat at the inside of the object itself, in usual cases by the dielectric effect of a high-frequency electromagnetic field produced from an oscillator provided within the vacuum container in which the object is enclosed. In the internal heating there will be a danger of spark discharge in such an electric field of substantial strength provided under substantially reduced air pressure. The maximum allowable output of a high-frequency oscillator, such as a magnetron, free from the danger of discharging is approx. 1W per gram of moisture contained in the object, the frequency being 2450 MHz. Since the maximum output of commercial magnetrons is 5 KWH or so at present, the available internal heating capacity will inevitably be insufficient for a practical speed of drying without a danger of electric discharging. If a large number of magnetrons with such small output are employed to increase the heating capacity, the vacuum container in which the magnetrons are enclosed will have to be so much larger as to increase the cost of equipment correspondingly. In either way, of heating, therefore, conventional freeze-drying is far from being satisfactory in respect of efficiency, effectiveness and/or cost.

There have been some attempts to speed up the drying process by continuously taking the solid objects in and out of the vacuum containers, but such attempts result in semi-continuous operation if a care is taken to avoid losing vacuum on the occasion of taking in and out, thus failing to meet the efficiency requirements of mass production sufficiently.

An object of the invention is to provide

[Price 25p]

fully continuous freeze-drying with sufficiently large heating capacity to provide for rapid drying without the danger of electric discharge in the vacuum or the need for enlargement of the vacuum container size.

According to the present invention there is provided a method of freeze-drying food and medical stuffs which comprises, in combination, the steps of: (a) charging a frozen object of such stuff into a container made of material having a substantially low dielectric loss, or high infrared ray permeability, (b) connecting said container to a first vacuum source and thereby evacuating said container of gaseous atmosphere to subject the object therein to a substantial degree of vacuum, (c) substantially maintaining the vacuum obtained in step (b) while disconnecting said container from said first source of vacuum and connecting it to a second vacuum source and passing said evacuated container with the object therein through an electromagnetic field or infrared field, according as the material has a low dielectric loss or a high infrared ray permeability, established in a non-evacuated tunnel while keeping the vacuum substantially constant within said container by continuous evacuation of gaseous atmosphere therefrom, thereby sublimating moisture out of the object and extracting the resulting vapour from the evacuated container, (d) disconnecting said container from said second vacuum source and (e) practicing at least steps (b), (c) and (d) in a continuous sequence for one container after another independently while moving a series of containers around a circular path with step (d) performed in said path with respect to each container being immediately followed by the carrying out of step (b) performed in said path with respect to another container.

The vacuum containers can be made of glass, ceramic material plastics or other similar material having a relatively low dielectric loss factor for high-frequency radiation.

Alternatively, the vacuum containers can be made of glass, plastics or other similar material having a substantially high permeability for infrared radiation. Preferred forms of the invention shown by way of example in the accompanying drawings in which:

Figure 1 is a vertical elevation partly in section of a freeze-drying apparatus embodying the present invention;

Figure 2 is a plan view of the apparatus of Figure 1;

Figure 3 is an enlargement, in vertical section, of a branch conduit and its relevant parts shown in Figure 1;

Figure 4 is an enlargement, in vertical section, or a portion of main conduit and its relevant parts shown in Figure 1;

Figure 5 is a sectional plan view taken on x5—x5 line in Figure 1;

Figure 6 is an enlargement, in vertical section, of vacuum containers and their relevant metallic reflectors of Figure 5;

Figure 7 is a schematic view to show piping for initial evacuation of air, and the rotary sequence of steps in the embodiment of Figure 1;

Figure 8 is a circuit diagram for automatic change-over of valves in the embodiment of Figure 1;

Figure 9 is a vertical section of another embodiment of the invention, with a lower portion cut away; and

Figure 10 is a sectional plan view taken on x10—x10 line of Figure 9, showing the rotary sequence of steps.

The embodiment shown in Figure 1 to 8 has an annular turn table 2 rotatable on a pair of annular rails 1 by means of wheels 31. An upper main conduit 3 is provided at the centre of the turn table 2, and is rotatable by a driving mechanism A. The main conduit 3 is provided with a plurality of branch conduits 4 in a generally radial arrangement at the top end thereof. The branch conduits 4 are supported on the turn table 2 at the open ends 4^1 (Figure 3) thereof, the ends 4^1 opening upward. A short conduit 6 is joined to the open end 4^1 of each branch conduit 4 by the intermediary of an electromagnetic valve 5. A rod 7 is secured to the short conduit 6 by means of a rib 7^1 at the lower end thereof, and is engageable with a holder 8 at the upper end thereof for the object 40 to be freeze-dried. The short conduit 6 is connected to an electromagnetic valve 9 for initial evacuation of air and also to another electromagnetic valve 10, for allowing air to be leaked into a container. The upper end of conduit 6 is provided with a flange 6^1 engaging with a flange 11^1 of a bell jar 11 by the intermediary of packing in a freely detachable relation. The bell jar 11 is a vacuum container made of glass, ceramic material or other similar material with substantially low dielectric loss.

A heating tunnel B in which atmospheric pressure exists extends over a part of the rotary path of bell jars 11 carried on the turn table 2 to permit the bell jars 11 to pass through it as the turn table 2 is rotated. The tunnel B is lined with metallic reflectors B2 on the inner walls thereof to prevent the escape of high-frequency radiation, and is provided with a slit B1 in the full length of the bottom thereof to accommodate and guide the bell jars 11. A plurality of high-frequency radiating oscillators B3 are provided on the side walls of tunnel B.

As shown in Figure 7, the turn table 2 is equipped with five pumps C1, C2, C3, C4, C5 for initial evacuation of air from the bell jars 11. The number of vacuum pumps is the same as the number of bell jars running in the initial evacuation process of the invention to be described later more particularly, and the total number of bell jars is an integral number times the number of bell jars running in the initial evacuation process. As best shown in Figure 7, the first initial evacuation valve 9 is connected to the vacuum pump C1 by way of a pipe C6. The second and subsequent three initial evacuation valves 9 are connected to the vacuum pumps C2, C3, C4, C5 by way of pipes C7, C8, C9, C10, respectively. The sixth valve 9 is connected to the pump C1 by way of pipe C6 again, and all the subsequent valves 9 are connected to the vacuum pumps similarly in this repeated order.

The turn table 2 is provided with the same number of micro-switches 12 (Figure 2) as bell jars 11, at the circumferential periphery thereof. As shown in Figure 8, each micro-switch 12 is combined with a four-way relay 13 which automatically changes-over a power source circuit 14 to contacts 12-1, 12-2, 12-3, 12-4, and again to 12-1 each time the micro-switch is actuated, the contact 12-1 being for actuation of the electromagnetic valve 9 in charge of initial evacuation of air from the bell jar 11, the contacts 12-2 and 12-3 for opening and closing of the electromagnetic valve 5 in charge of main evacuation of air from the bell jar 11, electro magnetic valve 10 for tion of the electromagnetic valve 10 for leaking air to the bell jar 11. Four microcontacts 15, 16, 17, 18 (Figure 2) are located around the turn table 2 in engageable relation with each of the micro-switches 12 as the turn table is rotated, as shown in Figure 2. The microcontacts are in such a circumferential arrangement in relation to the turn table 2 as in proportion to the time required for the four processes of initial evacuation, main evacuation, discharging, and charging.

The rotatable upper main conduit 3 is connected to a fixed lower conduit 20 by the intermediary of rotary joint 19. The lower main conduit 20 is connected to a plurality of cold traps 21, 21' in parallel relation by the intermediary of gate valves 24, 24', and the cold traps 21, 21' are connected to a vacuum pump 23 for main evacuation of air by way of conduit 22 and stop valves 25, 25'. Each cold trap has its own cooling system which comprises the trap 21 or 21' itself, a cooling tube 35 or 35', an automatic flow regulating valve 36 or 36', a drain valve 38 or 38', a feed stop valve 26 or 26', a return stop valve 27 or 27', and a defrost valve 37 or 37'. The cooling systems are all connected to a refrigerant heat pump 32 by way of a feed pipe 33 and a return pipe 34. The cold traps are changed over by the stop valves 24, 24', 25, 25', 26, 26' and 27, 27' to put one of them into service while the others are out of service.

As best shown in Figure 6, high-freqency radiation is shielded from leakage by means of metallic reflectors 28, 29 and 30. The reflector 28 (Figures 2 and 5) is an annular metallic plate extending between the bell jars 11 to shield the slit B1 at the bottom of heating tunnel B. The reflectors 29 are annular metallic plates surrounding each bell jar 11 to shield holes 28' which is provided in the reflector 28 to allow the flange 11' of bell jar 11 to pass through when the jar is open and closed. The reflectors 30 are annular metallic plates fixed to the rods 7 to shield the open bottom end of bell jar 11. The reflectors 29 and 30 are located at almost the same level, with the inner edge 29' of the former and the outer edge 30' of the latter being bent downward to be in such an opposite relation with each other notwithstanding the intermediary of bell jar wall as to define a clearance between them which is more than ¼ the wavelength and narrower than the full amplitude of the applied high-frequency energy and less than equal to the said wavelength. The high-frequency radiation is also shielded from leakage by means of self-closing doors B4, B5 and B6, B7 made of metallic plate or mesh, arranged at both ends of heating tunnel B as shown in Figure 5. All the shielding members 28, 29, 30, B2, B4, B5, B6, B7 are thermally insuated.

As shown in Figure 4, the upper main conduit 3 is provided with a slidable contact mechanism D to supply power to the driving motors of vacuum pumps C1, C2, C3, C4, C5 and the circuits 14 connected to relays 13. The driving mechanism A for rotating the main conduit 3 comprises a motor A1, a speed variator A2, a toothed pinion A3 and a toothed gear A4. The numeral 39 in Figure 1, indicates a rail for guiding the bell jars 11 as the turn table 2 goes round.

In the operation of freeze-drying with reference to Figures 1 to 8, each relay 13 is initially set at a desired arrangement, for instance, to connect the circuit 14 to the contact 12-1 to actuate the valve 9 for initial evacuation of air the moment one of the microswitches 12 touches the microcontact 15 located at the point (a) of Figure 7. The vacuum pump 23 reduces pressure in the main evacuation system which consists of electromagnetic valves 5, branch conduits 4, upper main conduit 3, joint 19, lower main conduit 20, cold trap 21 and connection conduit 22. The vacuum pumps C1, C2, C3, C4, C5 reduce pressure in the pre-evacuation pipes C6, C7, C8, C9, C10, re-

spectively. The upper main conduit 3 is rotated by the driving mechanism A while the lower main conduit 20 remains stationary. The turn table 2 is rotated together with the upper main conduit 3 in the direction arrow-marked in Figure 1, carrying the bell jars 11 thereon. As the turn table 2 goes round, the bell jars 11 pass through the heating tunnel B with atmospheric pressure on a given part of the guide rail 39 and are detached upward off the flanges 6^1 of short conduit 6 on another given part of the guide rail 39.

While a bell jar 11 is detached from the short conduit 6, that is, in the charging process from (f) to (a) of Figure 7, a holder 8 containing a frozen object 40 is put on the top of rod 7. Then the bell jar 11 is lowered down to the flange 6^1 of short conduit 6 as it approaches the end (a) of the charging process, now enclosing the object 40 therein.

At the point (a) a microswitch 12 touches the microcontact 15 to cause the relay 13 to change-over to the contact 12-1 to open the electromagnetic valve 9. Air is then evacuated out of the bell jar 11 by way of the opened valve 9 and its relevant pipe C6 by the action of vacuum pump C1. In this manner in the initial evacuation process from (a) to (b) of Figure 7, the bell jar 11 is evacuated of air nearly down to the higher vacuum which is standing in the branch conduit 4, thereby balancing pressure at both sides of the electromagnetic valve 5 to facilitate the succeeding opening of valve 5 while unbalancing pressure inside and outside of the wall of the bell jar 11 to keep the jar 11 firmly on the flange 6^1 of short conduit 6.

At the point (b) a microswitch 12 touches the microcontact 16 to cause the relay 13 to change-over to the contact 12-2 to open the electromagnetic valve 5 while allowing the electromagnetic valve 9 to close, thus the bell jar 11 is transferred from the initial evacuation process into the main evacuation process without affecting the pressure at both sides of electromagnetic valve 5. In the main evacuation process from (b) to (e) of Figure 7, the bell jar 11 is always kept at a given substantial vacuum by the action of vacuum pump 23. The electromagnetic valve 5 is kept fully opened from (b) to (d) of Figure 7, by the action of a limit switch (not shown). After passing the point (e) the bell jar 11 opens the shielding doors B4, B5 and enters the heating tunnel B along the slit B1. As the bell jar 11 goes through the electromagnetic field provided by the high-frequency oscillators B3 in the tunnel B, the object 40 which has a substantially high dielectric loss is heated internally by the effect of high-frequency flux to sublimate the frozen moisture thereof under the vacuum within the bell jar 11.

More particularly in the heating tunnel B, the object 40 which is kept in a vacuum of approx. 0.1 mm Hg within the bell jar 11 goes through an electromagnetic field defined by the shielding members 28, 39, 30, B2, B4, B5, B6, B7, and is exposed to high-frequency flux flowing through the wall of bell jar 11 which is made of a material with a low dielectric loss. Electromagnetic energy is converted into thermal energy in proportion to the strength of electromagnetic field, frequency of the field, and dielectric loss factor of the object, whereby the temperature of the object is raised approx. to −20° or −25°C which is higher than the saturation temperature of moisture at the existing pressure and therefore the frozen moisture is quickly sublimated out of the object 40. The more moisture is sublimated, the more the dielectric loss is decreased and accordingly the less the object is heated thereby overheating will be largely avoided. Thus the object is dried sufficiently into a porous solid object, before the bell jar 11 opens the shielding doors B6, B7 and leaves the tunnel B.

The vapour sublimated out of the object 40 is drawn from the bell jar 11 to cold trap 21 by way of the electromagnetic valve 5, branch conduit 4, upper main conduit 3, joint 19 and lower main conduit 20. The condensable fractions are trapped on the cooling tube 35, while non-condensable gas is further drawn to the vacuum pump 23 by way of the conduit 22, and therefore the main evacuation system is always kept at a given substantial vacuum. When so much condensate is trapped on the cooling tube 35 as to lower the trapping capacity substantially, the trap 21 is put out of service and another trap 21^1 is put into service instead of the control of relevant stop valves 24, 21^1, 25, 25^1, 26, 26^1 and 27, 27^1.

At the point (d) immediately after the tunnel B, a microswitch 12 touches the microcontact 17 to have the relay 13 change-over to the contact 12-3 to begin to close the electromagnetic valve 5, which is completely closed before a microswitch 12 touches the microcontact 18 at the point (e) thus isolating the bell jar 11 completely from the branch conduit 4 wherein a given substantial negative pressure is always maintained.

At the point (e) a microswitch 12 touches the microcontact 18 to cause the relay 13 to change-over to the contact 12-4 to open the electromagnetic valve 10. Clean dry air is then leaked into the bell jar 11 by way of the opened valve 10 and a filter (not shown) provided on the valve 10. Thus atmospheric pressure is re-established within the bell jar 11 and therefore pressure is balanced within and without the bell jar 11 to facilitate the succeeding detaching of

bell jar 11 from the flange 6^1 of short conduit 6^1, ending the discharging process designated from (e) to (f) in Figure 7.

After the discharging process, the bell jar 11 is returned back again to the charging process designated from (f) to (a) in Figure 7. In the charging process, the bell jar 11 is opened upward and the holder 8 with the dried object 40 is taken off, and in place another holder with a new object is put on, the rod 7. The bell jar 11 with the new object 40 then goes into the next cycle, the electromagnetic valve 10 being allowed to close at the point (a) where the microswitch 12 touches the microcontact 15. As the turn table 2 is rotated continuously, each of the bell jars 11 carried on it goes through the process of charging, initial evacuation, main evacuation and leak in sequence, thereby discharging the dried products continuously.

As described above, there are four processes in freeze-drying making use of the embodiment shown in Figures 1 to 8; namely, charging process designated from (f) to (e), initial evacuation process from (a) to (b), main evacuation process from (b) to (e), and discharging process from (e) to (f). There are always a plurality of bell jars 11 in each of the four processes. And there are always five bell jars 11 in the pre-evacuation process of the present embodiment, each bell jar pre-evacuated of air by an independent vacuum pump C1 C2 C3 C4 or C5 in such a manner that, as one jar goes out of the initial evacuation process, another jar comes into the process to be evacuated of air by the same pump used for the leaving jar. Therefore different pressures exist in five jars running in the initial evacuation process. This pumping quickens the initial evacuation time for each jar.

The heating tunnel B may be dividtd transversely into a plurality of longitudinal compartments, each compartment providing a different strength of electromagnetic field in inverse proportion to the dielectric loss of the object 40 which usually decreases as the object 40 gets more and more dried through the heating course of tunnel B, so as to almost completely exclude the possibility of over-heating the object and making it possible to efficiently dry a wide range of objects with different dielectric losses.

The embodiment shown in Figures 9 and 10 is especially for freeze-drying medical stuffs in glass ampoules permeable to infrared radiation by the use of infrared radiation as the heating source for sublimation of moisture. Medical stuffs of particular properties and bacterial strains are often subject to denaturing of protein or sterilisation of such bacteria when heated internally by the dielectric effect of high-frequency radiation through such sterilisation is usually most desirable for general food stuffs. In such particular cases, external heating with infrared radiation will be preferable in freeze-drying. In addition, glass ampoules or similar containers require a sealing process after the object is freeze-dried. These requirements are fulfilled by the embodiment shown in Figures 9 and 10.

The embodiment in Figures 9 and 10 has a construction and function fundamentally similar to the one in Figures 1 to 8. Therefore similar members are designated by same reference numerals.

In Figure 9, an upper main conduit 3 is provided at the centre of a turn table 2 which is rotatable around an annular rail 1 by means of wheels 31. The upper main conduit 3 is rotable by a driving mechanism including a driven shaft A5, a toothed pinion A3 and a toothed gear A4. A plurality of branch conduits 4 are connected to the upper main conduit 3 by the intermediary of straight conduits 43 and an annular conduit 42 which is supported on the turn table 2. Each branch conduit 4 is open downward, and its open end 4^1 is connected to a short conduit 6 by the intermediary of an electromagnetic valve 5. The short conduit 6 is connected to an electromagnetic valve 9 for pre-evacuation and also to another electromagnetic valve 10 for leaking air thereinto.

The embodiment in Figures 9 and 10 is provided with a plurality of attachments E for loading ampoules 41 and also a mechanism F for sealing the ampoules 41. Each ampoule loading attachment E comprises a joint E1, an arm E2 secured to the turn table 2, an ampoule-connecting pipe E3 connected to the short conduit 6 by the intermediary of joint E1 and supported by the arm E2 in rotatable relation therewith, a friction wheel E4 fixed to the pipe E3, and a rubber connector E5 affixed at the lower end of pipe E3 to hold an ampoule 41 tightly. The ampoule sealing mechanism F comprises a belt F1 to revolve the ampoule 41 and a burner F2 to seal the ampoule 41.

A heating tunnel B open to automatic pressure is installed under a part of the rotary path of the ampoule-connecting pipes E3 carried by the turn table 2 to permit the lower parts of the pipes E3 and loaded ampoules 41 to pass through it as the turn table 2 is rotated. The tunnel B is provided with a slit B1 therein for the full length of the top thereof to guide the ampoule connecting pipes E3, and is also equipped with a plurality of infrared radiation radiators B8 on the side walls thereof to provide an irradiation field therein.

The rotary upper main conduit 3 is con-

nected to a stationary lower main conduit 20 by the intermediary of a joint 19. The embodiment is further provided with vacuum pumps and pipings for initial evacuation of air; vacuum pump, refrigerator, cold traps, valves and piping for main evacuation, electric relays and circuits including microswitches and microcontacts to switch the processes. These are not shown in Figures 9 and 10 because they are similar to those of Figures 1 to 8.

In the operation of freeze-drying in reference to Figures 9 and 10, initially the electric relays are pre-arranged for the charging process from (h) to (a), initial evacuation process from (a) to (b^1), main evacuation process from (b) to (e), sealing process from (e^1) to (f), and discharging process from (g) to (h).

In the charging process an ampoule 41 containing a frozen object 40 is put on a connecting pipe E3 by means of the affixed rubber connector E5. At the point (a) the electromagnetic valve 9 is opened to initial evacuate air out of the ampoule 41 by way of the connecting pipe E3 and short conduit 6. At the point (b^1) the valve 9 is closed to finish the initial evacuation process. At the point (b) the electromagnetic valve 5 is opened for main evacuation of air by way of the branch conduit 4 to keep the inside of ampoule 41 at a given substantial vacuum. The ampoule 41 then goes through the heating tunnel B from (c) to (d), during which it is exposed to infrared radiation from the radiators B8. The object 40 heated externally by the infrared radiation has its frozen moisture sublimated in the vacuum within the ampoule 41. Thus the object is dried before the ampoule 41 goes out of the tunnel B. At the point (e) the electromagnetic valve 5 is closed to finish the main evacuation process. At the point (e^1) the electromagnetic valve 10 is opened to introduce clean dry air or nitrogen gas into the ampoule 41, and therefore the ampoule 41 is at atmospheric pressure therein. The process of refilling the ampoule with air or other gas is finished at the point (f).

In the sealing process designated from (g) to (h), the ampoule 41 is revolved on the connecting pipe E3 by means of the friction wheel E4 in contact with the belt F1, and the ampoule 41 is sealed by the flame from the burner F2.

The sealed ampoule 41 with dried object 40 is taken off, and in place another with a new object is put on, the connecting pipe E3 with rubber connector E5. The ampoule 41 with the new object 40 then goes into the next cycle. As the turn table 2 is rotated continuously, the dried and sealed products are delivered continuously.

The infrared radiation radiators B8 may be replaced by a means for producing an electromagnetic field to heat the object internally by the dielectric effect.

The embodiment in Figures 9 and 10 can be used for various containers merely by interchanging of the loading attachments E.

It will thus be seen that freeze-drying in accordance with the invention provides fully continuous operation with sufficiently large heating capacity without running any danger of electric discharge in vacuum and without requiring any enlargement of vacuum equipment size.

WHAT WE CLAIM IS:—

1. A method of freeze-drying food and medical stuffs which comprises, in combination, the steps of:

(a) charging a frozen object of such stuff into a container made of material having a substantially low dielectric loss, or high infrared ray permeability,

(b) connecting said container to a first vacuum source and thereby evacuating said container of gaseous atmosphere to subject the object therein to a substantial degree of vacuum,

(c) substantially maintaining the vacuum obtained in step (b) while disconnecting said container from said first source of vacuum and connecting it to a second vacuum source and passing said evacuated container with the object therein through an electromagnetic field or infrared field, according as the material has a low dielectric loss or a high infrared ray permeability, established in a non-evacuated tunnel while keeping the vacuum substantially constant within said container by continuous evacuation of gaseous atmosphere therefrom, thereby sublimating moisture out of the object and extracting the resulting vapour from the evacuated container,

(d) disconnecting said container from said second vacuum source and

(e) practising at least steps (b), (c) and (d) in a continuous sequence for one container after another independently while moving a series of containers around a circular path with step (d) performed in said path with respect to each container being immediately followed by the carrying out of step (b) performed in said path with respect to another container.

2. A method as claimed in Claim 1, wherein between the steps (d) and (e) gas is allowed to leak into the container so that the pressure therein reaches atmospheric pressure, and the dried object is removed.

3. A method as claimed in Claim 1, wherein between the steps (d) and (e) the container is sealed with the freeze-dried object therein.

4. A method of freeze-drying food and

medical stuffs, substantially as herein described with reference to the accompanying drawings.

5. An apparatus for freeze-drying food and medical stuffs by the method claimed in Claim 2, comprising an upper central rotary conduit rotatable by a driving mechanism, a lower central stationary conduit connected with said upper central conduit by the intermediary of a rotary joint, a turn table rotatable together with said central rotary conduit, a plurality of conduits branched from said upper central conduit at one end and supported on said turn table at the other open end, a plurality of short conduits joined respectively with said branch conduits at said open ends supported on said turn table, a plurality of containers to be engaged respectively on said short conduits in detachable relation and to be moved around a horizontally circular path on said turn table, a tunnel having atmospheric pressure therein and equipped with a plurality of high-frequency oscillators and shielding means to provide an electromagnetic field therein or with a plurality of infrared ray radiators to provide an irradiation field therein, and means to move said containers vertically as they move around said horizontally circular path in such a manner as to detach each of said containers from an associated said short conduit while it moves around a first part of said circular path and to engage it with said short conduit while it moves along the second part thereof, each of said short conduits being provided with means therein for supporting a holder for the object, each of said holders with a frozen object thereon being put on and off said supporting means in said short conduit while said container is disengaged from said short conduit along the first part of said circular path, said containers being made of a material with substantially low dielectric loss, or high infrared ray permaability according as the apparatus is provided with high-frequency oscillators or infrared ray radiators, said lower central conduit being connected to a first vacuum pump by way of a cold trap and relevant pipings to evacuate said short conduits of air to a substantially reduced pressure, each of said short conduits being connected with a trio of valve means, one of which is operable to connect said short conduit to a vacuum pump to initially evacuate said container of air from atmospheric pressure down to a substantially reduced pressure while said container moves along the second part of said circular path, another of which is intermediate said short conduit and said branch conduit and is operable to cause the evacuation of said container of air by means of a second vacuum pump to keep substantially reduced pressure within said container while it moves around a third part of said circular path, and the last one of which is connected to an air or other gas source, to allow such air or other gas to leak into said container so that the pressure therein rises from the substantially reduced pressure up to atmospheric pressure while the container moves around a fourth part of said circular path, said tunnel being located in the third part of said circular path to heat the object either by dielectric heating effect of high-frequency radiation or by the infrared radiation transmitted through said container to sublimate frozen moisture out of the object to dry the same, the fourth part of said circular path being adjacent to the first part thereof.

6. An apparatus according to Claim 5 wherein the number of said vacuum pumps connected to said short conduits by way of piping is same as the number of said containers running along the second part of said circular path, each of said vacuum pumps evacuating one of said containers independently in a manner that, as one container goes out of the second part of said circular path, another container comes therein to be evacuated of air by the same vacuum pump used for the leaving one.

7. An apparatus as claimed in Claim 5 wherein the said last one of the trio of valve means is an electromagnetic valve and said turn table is provided with the same number of microswitches as said containers at the periphery thereof to be in engageable relation with contact means arranged along said circular path, each of said microswitches being combined with an electric relay means to actuate and re-set said electromagnetic valve every time one of said microswitches touches one of said contact means as said container moves around said circular path thereby causing said evacuating and leaking of air in the respective parts of said circular path.

8. An apparatus for freeze-drying foods and medical stuffs frozen and dispensed in containers made of a material with substantially low dielectric loss or substantially high permeability for infrared rays by the method according to claim 3, comprising an upper central rotary conduit rotatable by a driving mechanism, a lower central stationary conduit connected with said upper central conduit by the intermediary of a rotary joint, a turn table rotatable together with said central rotary conduit, a plurality of conduits branched from said upper central conduit at one end and supported on said turn table at the other open end, a plurality of short conduits joined respectively with said branch conduits at said open ends supported on said turn table, a plurality of attachments respectively secured to said short conduits to carry said containers

around a circular path as said turn table is rotated, a tunnel having atmospheric pressure therein and equipped with a plurality of high-frequency oscillators and shielding means to provide an electromagnetic field therein or with a plurality of infrared ray radiators to provide an irradiation field therein, means to seal said containers with the objects therein respectively before they are unloaded from said attachments, and means to move each said container on and off said attachment as it moves around a first part of said circular path, said lower central conduit being connected to a first vacuum pump by way of a cold trap and relevant piping to evacuate said short conduits of air to a substantially reduced pressure, each of said short conduits connected to a trio of valve means, one of which is operable to connect said short conduit to the first vacuum pump to pre-evacuate said container of air from atmospheric pressure down to a substantially reduced pressure while said container moves around a second part of said circular path, another of which is intermediate said short conduit and said branch conduit and is operable to cause the evacuation of said container of air by means of a second vacuum pump to keep substantially reduced pressure within said container while it moves around a third part of said circular path, and the last one of which is connected to an air or other gas source to allow such air or other gas to leak into said containers so that the pressure therein rises from the substantially reduced pressure up to atmospheric pressure while the container moves around a fourth part of said circular path, said tunnel being located in the third part of said circular path to heat the object either by the dielectric heating effect of high-frequency radiation or by the infrared radiation transmitted through said container to sublimate frozen moisture out of the object to dry the same, the fourth part of said circular path being adjacent to the first part thereof, and the sealing means being located in the portion of the fourth part which is adjacent the first part.

9. An apparatus for freeze-drying food and medical stuffs, substantially as herein described with reference to Figures 1 to 8 or Figures 9 and 10 of the accompanying drawings.

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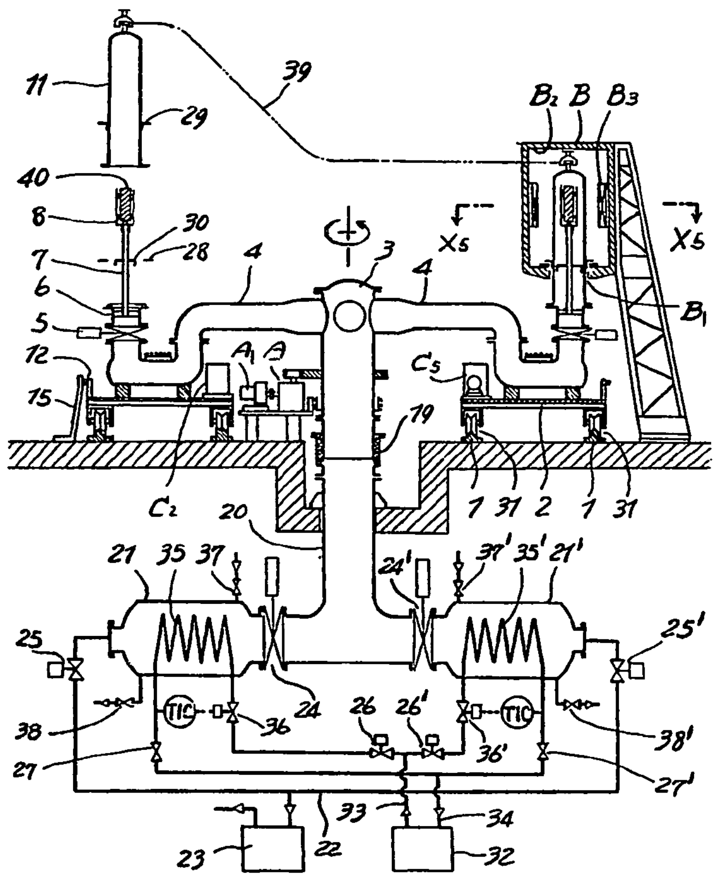
FIG. 1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39
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8
30
7
28
6
5
72
15
4
3
4
B2 B B3
X5
X5
B1
A1 A
C5
19
C2
20
7 31 2 7 31
21 35 37
24'
37' 35' 21'
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TIC
TIC
38
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26 26'
36'
38'
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27'
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22
32

1315545 COMPLETE SPECIFICATION

5 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 2

FIG. 2

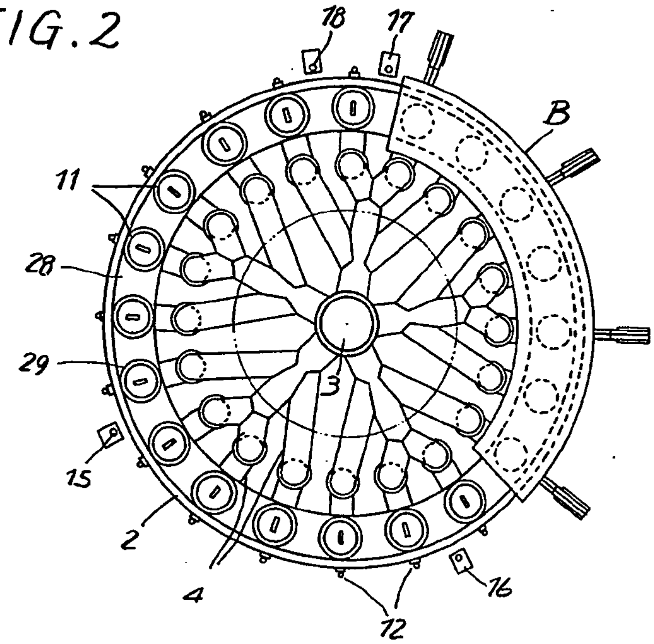


FIG. 3

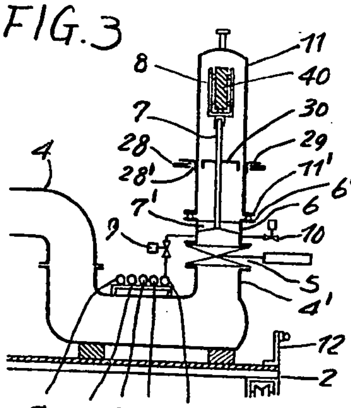


FIG. 4

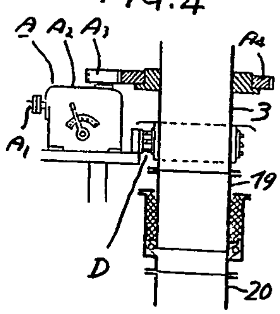


FIG. 5

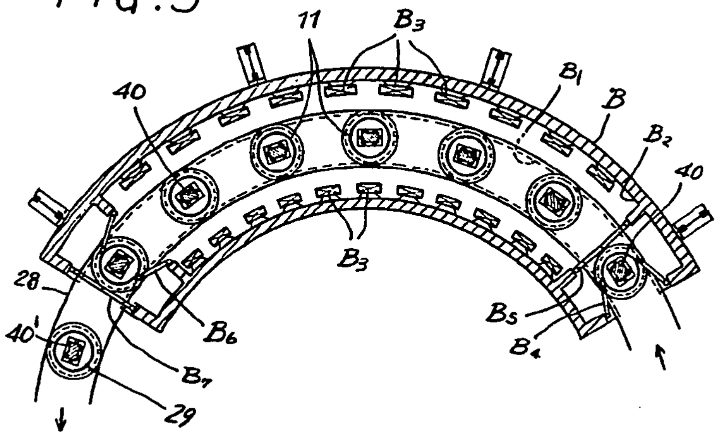


FIG. 6

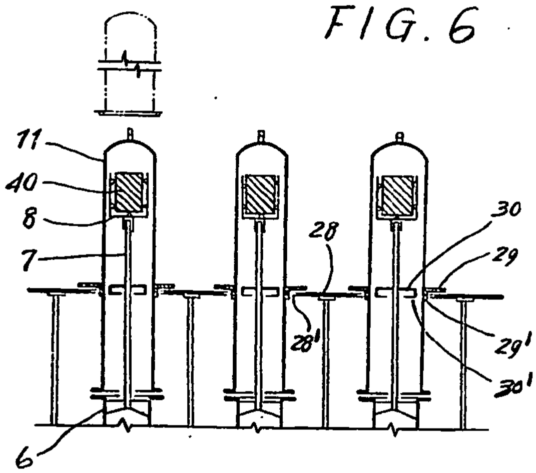
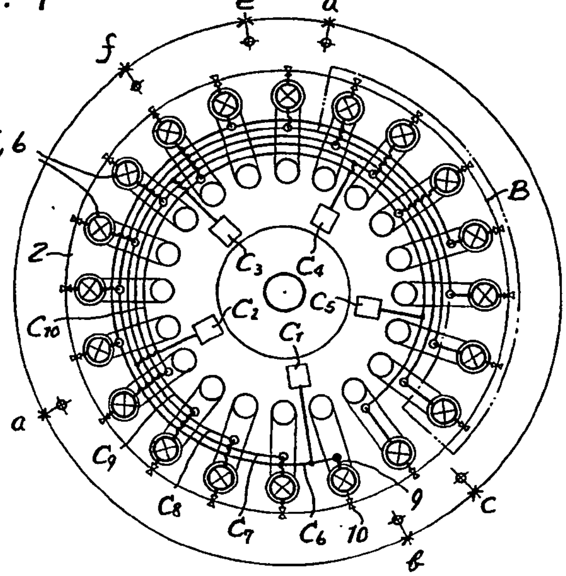


FIG. 7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d
f
5,6
B
2
C_3
C_4
C_2
C_5
C_{10}
C_1
a
C_9
9
C
C_8
C_7
C_6
10
b

FIG. 8

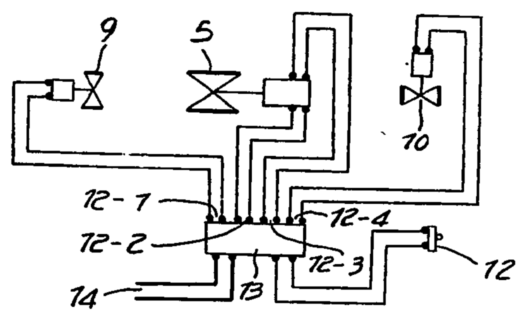
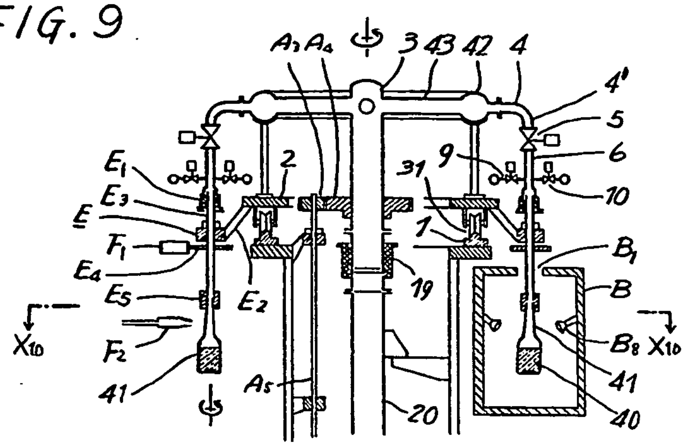

9
5
10
12-1
12-4
12-2
12-3
12
14
13

FIG. 9


A1 A4
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42
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4'
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6
9
10
31
1
2
E1
E3
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E4
E5
E2
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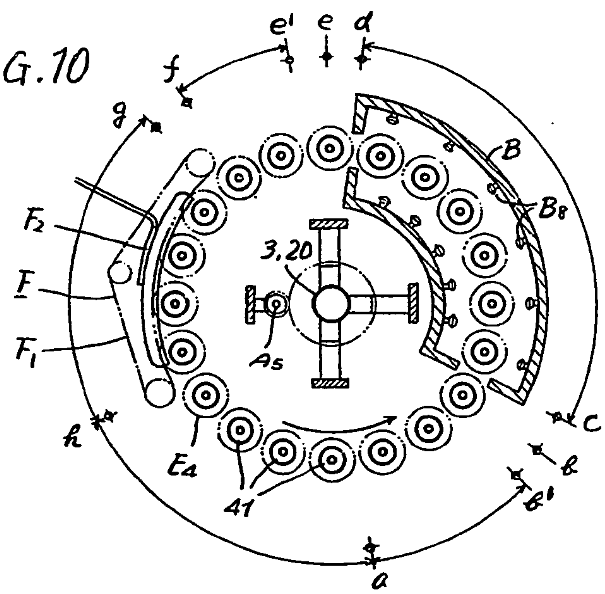
B1
B
B8
X10
F2
41
40
A5
20

FIG. 10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f
g
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F
F1
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A5
h
E4
41
c
b
b'
a